Atmospheric correction in the presence of absorbing aerosols, and enhancement quantification from multi-angle, polarimetric observations

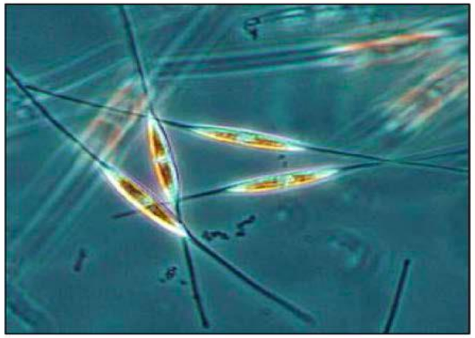
PI: Olga Kalashnikova

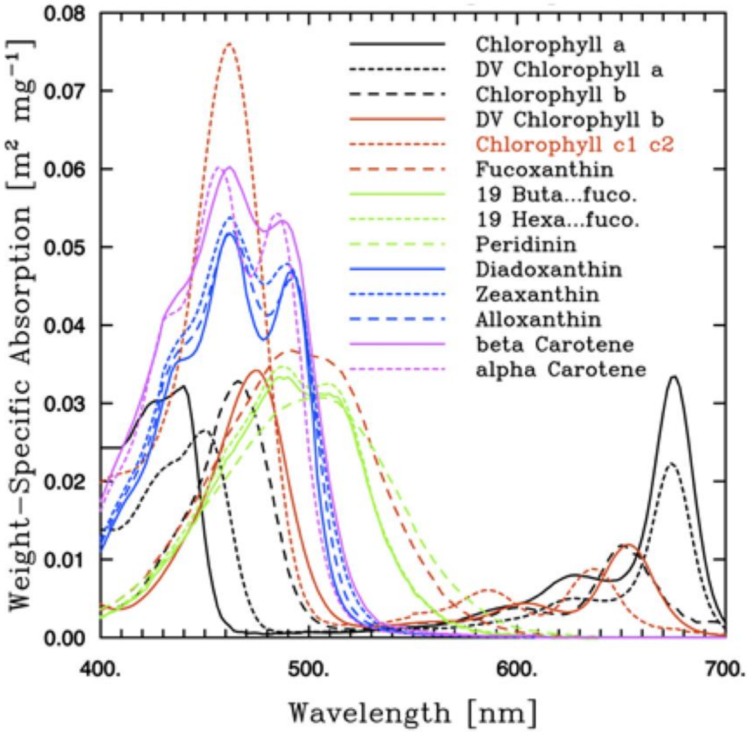
Co-Is: Feng Xu, Anthony Davis, Michael Garay

Collaborators: David Diner and Oleg Dubovik

Jet Propulsion Laboratory
California Institute of Technology

UV-short VIS spectra are needed for ocean characterization





Devred et al. [2013]

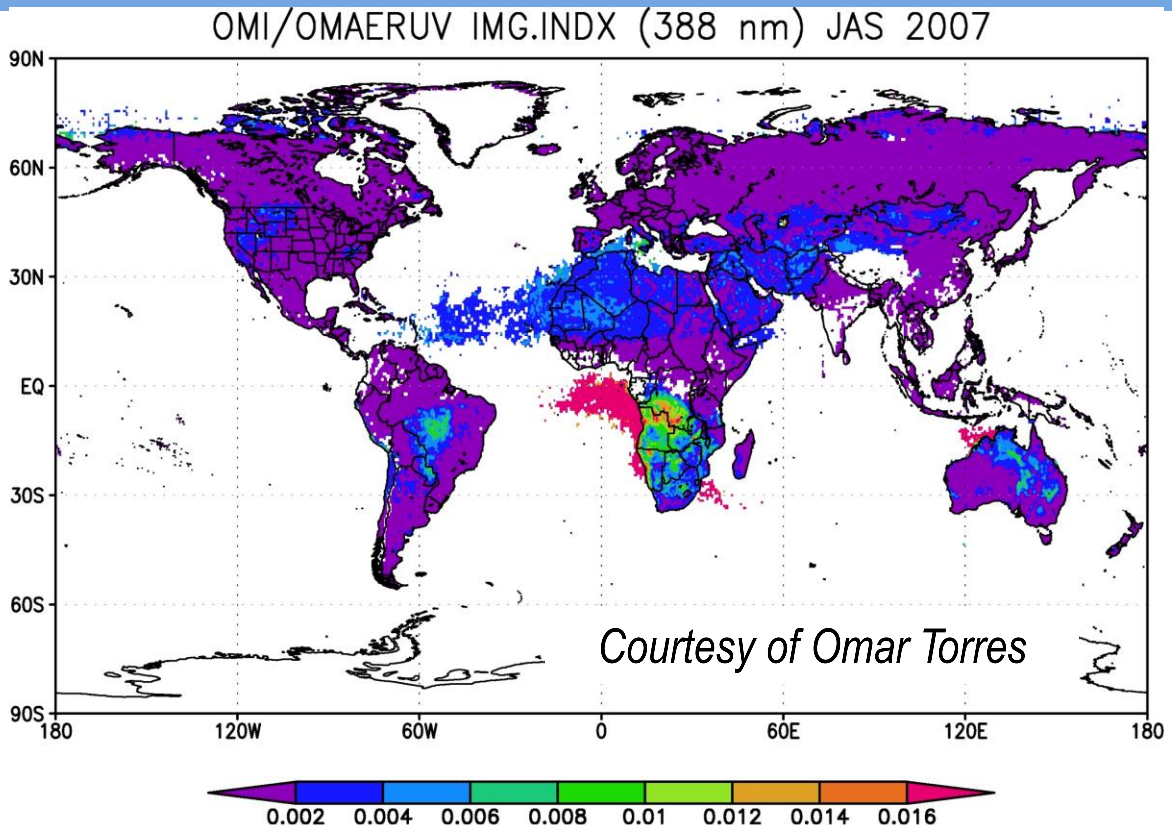
Blue and near-UV spectra contain information on accessory (non-chlorophyll) pigments, and can be used to separate chlorophyll and colored dissolved organic matter, and characterize phytoplankton taxonomy.

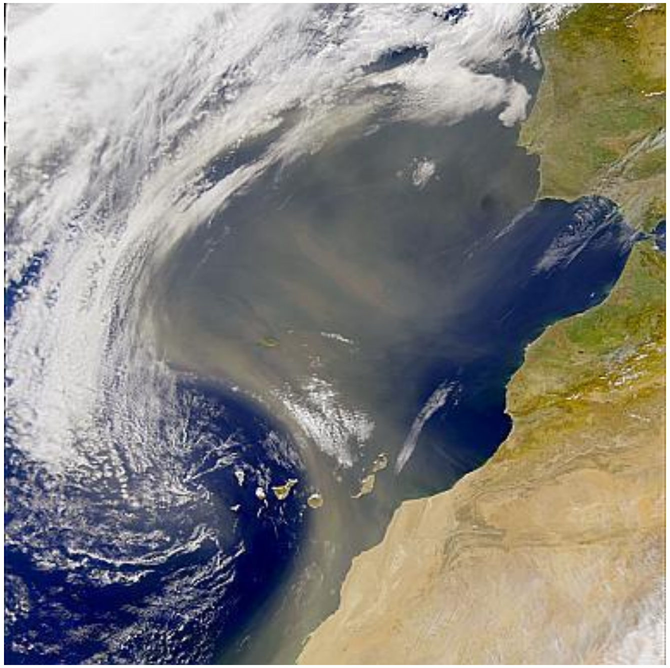
…**but atmospheric interference might make this challenging**

B. Mitchell, UCSB: Retrieving UV-absorbing mycosporine amino acids, algal proteins, and particle size distributions is needed to specify phytoplankton functional groups and plankton ecosystem structure.

S. Maritorena, UCSB: Dissolved organic matter and absorbing aerosols both absorb in the UV, which may limit the ability to differentiate them.

Outstanding questions

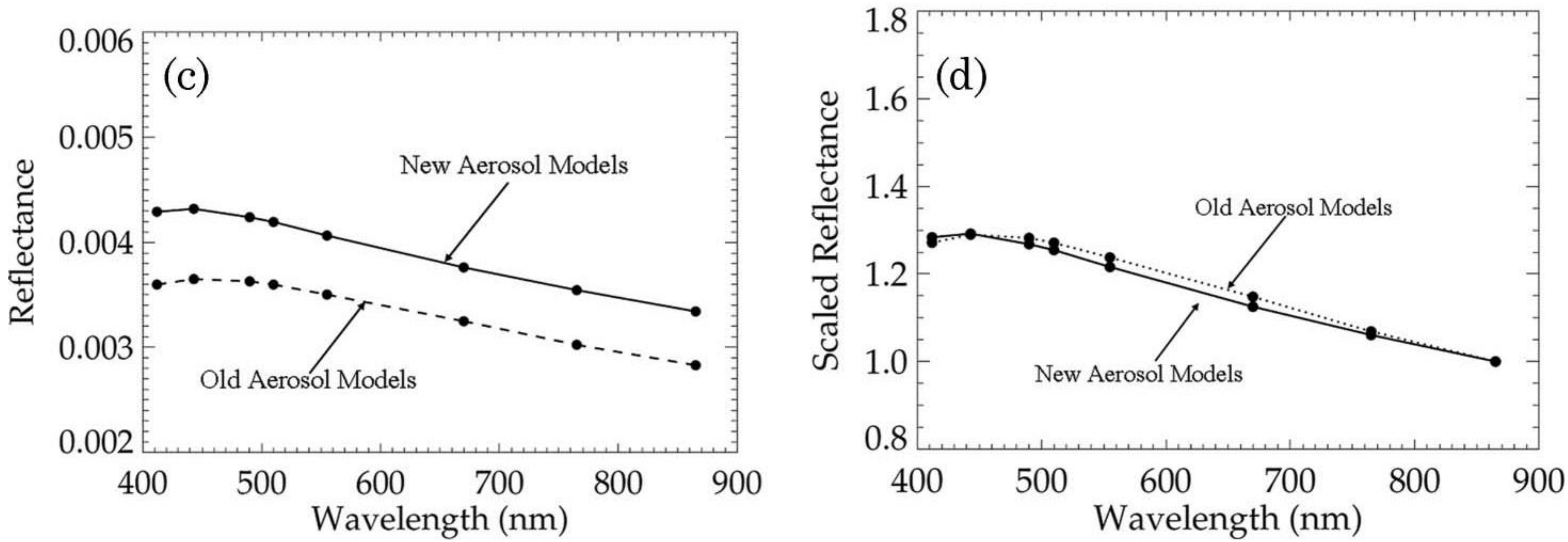




- How large are potential ocean reflectance biases from unaccounted aerosol absorption in the near-UV?
- Can multi-angle polarimetry help improve ocean color retrievals in presence of absorbing aerosols?

Atmospheric correction

The goal of atmospheric correction (AC) is to convert observed top-of-atmosphere spectral radiance to remote sensing reflectance (R_{rs}) over the NUV-VIS spectral regime



TOA reflectance computed from old (M70) and new (Rh80M06) aerosol models

Ahmad et al. [2010]

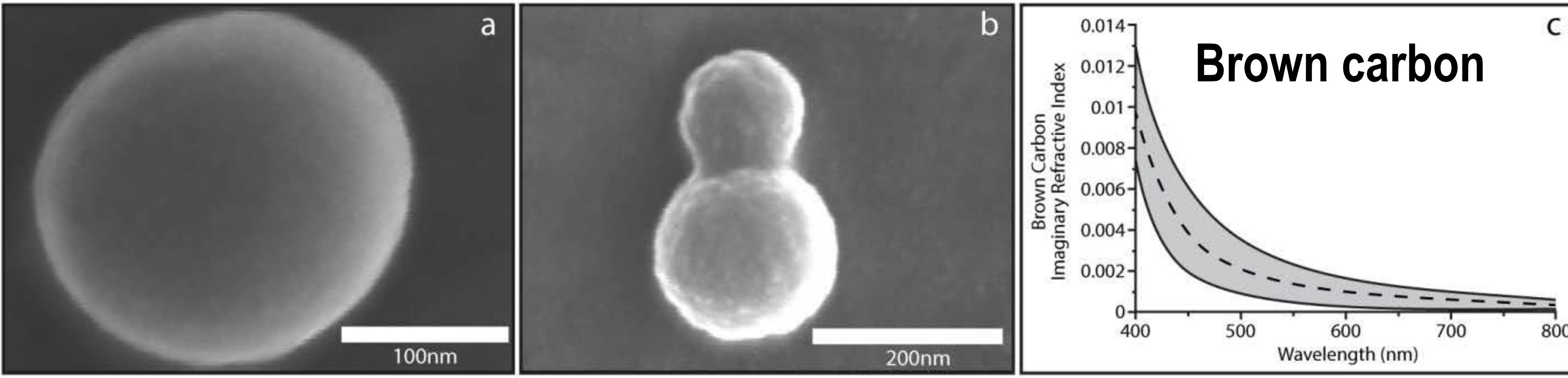
<u>Current NASA atmospheric correction approach</u>

- Obtain AOD and Aerosol Type from Red-NIR bands
- Extrapolate to Blue, UV (for next-generation instrument)
- Correlate with surface reflectivity at (MOBY) surface buoy

works well for non-absorbing aerosols or aerosols whose absorption does not change with wavelength

"Problematic" aerosols

Dust and brown carbon strongly absorb toward UV

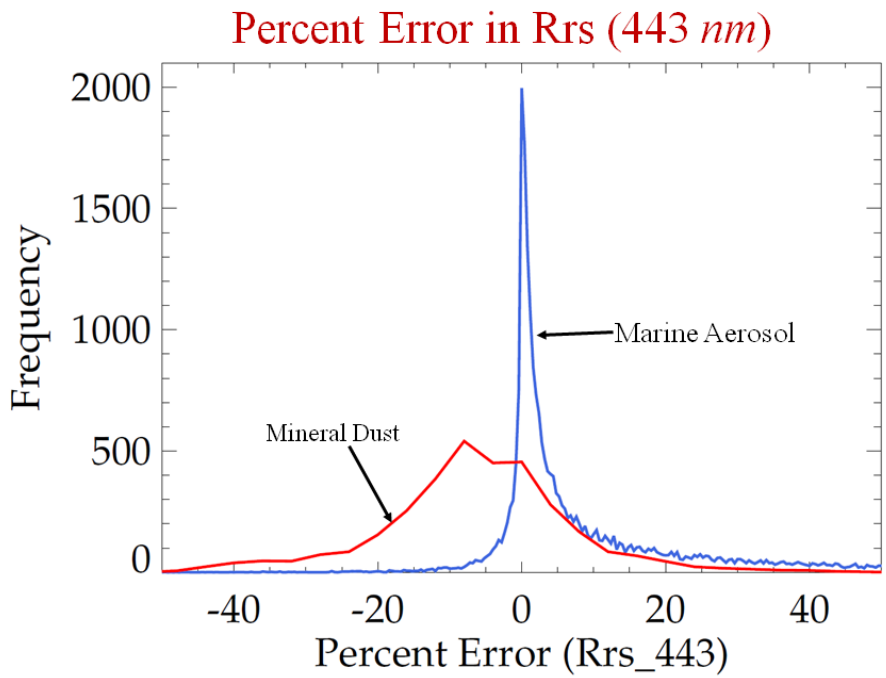


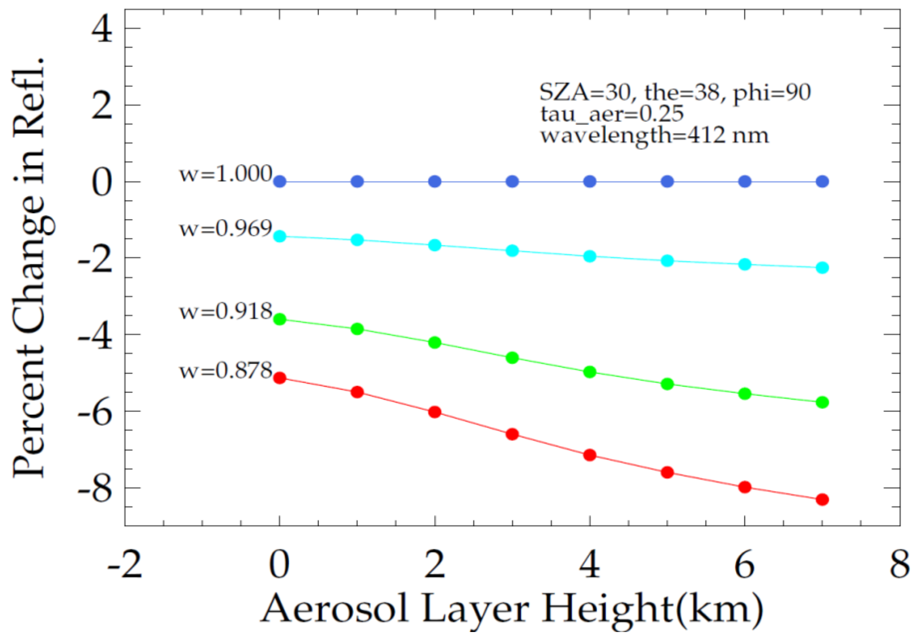
Courtesy of Rajan Chakrabarty

2 µm

Wagner et al. [2012]

GW94 atmospheric correction algorithm results

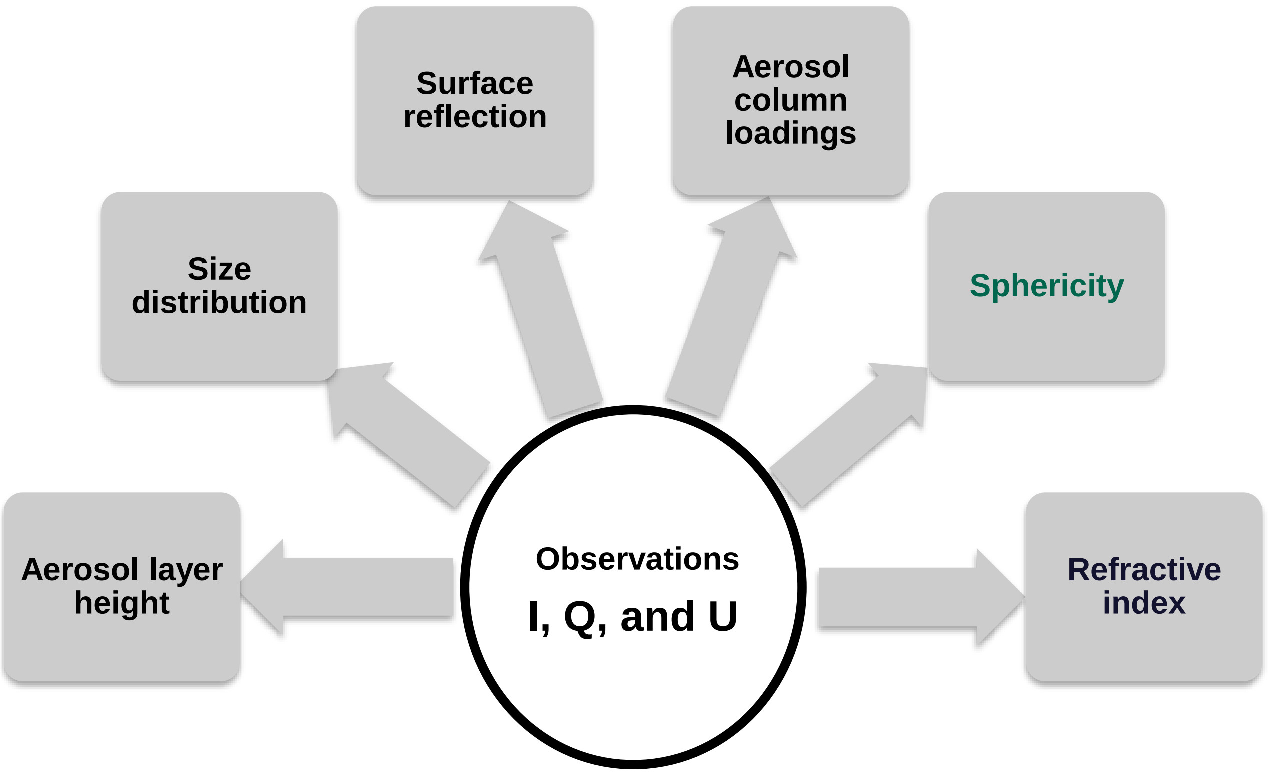




- Atmospheric correction algorithm produces large error in the retrieved spectral R_{rs} in presence of dust with a peak frequency ~10% . For marine aerosols, the error is ~ 2%, which is well within the stated goal.
- For τ_A=0.25, an error of 1 km in aerosol layer height would change the TOA reflectance by ~ 0.7%. This will result in ~7% change in water-leaving radiance.

Z. Ahmad and B. Franz, AGU Ocean Science, 2016

Why multi-angle polarimetry?



- Multiangle polarimetry distinguishes atmosphere and surface absorption in the UV-VNIR
- We expect a polarimeter to provide a risk reduction for ocean color retrievals at short wavelengths and for coastal waters

"…algorithms utilizing high-accuracy polarization as well as radiance measurements are much less dependent on the availability and use of a priori information and can be expected to provide a physically based retrieval of aerosol characteristics…" Mishchenko and Travis [1997]

What was done and ongoing analysis

- Multi-angle polarimetric sensitivity studies to aerosol properties (SOS)
- RT Markov-Chain coupled ocean-atmosphere model development
- Retrievability studies (Markov-Chain)
- Analysis of information content of AirMSPI observations
- New AirMSPI data collection and analysis
- O_2 A-band sensitivity to aerosol and cloud heights (see Anthony Davis presentation)

Theoretical sensitivity studies (Z-scores)

$$z_i = \frac{\left| f(\theta_i) - f_{\mathrm{ref}}(\theta_i) \right|}{\sqrt{\sigma_f^2(\theta_i) + \sigma_{f_{\mathrm{ref}}}^2(\theta_i)}}$$

f and f_{ref} represent the BRF or pBRF corresponding to different observational situations, θ_i represents the viewing angle and σ is the uncertainty

$$BRF = \frac{\rho I}{\mu_0 F_0} \qquad pBRF = \frac{\rho I_{\mathrm{pol}}}{\mu_0 F_0} \qquad I_{\mathrm{pol}} = \sqrt{Q^2 + U^2} \qquad DOLP = \frac{I_{\mathrm{pol}}}{I}$$

$\sigma_I = 1.5\%$

$\delta_{DOLP} = 0.005$

Kalashnikova et al., JQSRT, 2011

We also use the angular average of z-scores in the range [-75°,75°]

The values of *z* have a simple statistical interpretation in that they express the (absolute) difference between two measurements as a function of the standard deviation of the measurements.

Z-scores above 3 indicate distinguishability between two observations (e.g., observable differences in measurements of two different aerosol heights or two different absorption types)

Phase matrices as function of wavelength

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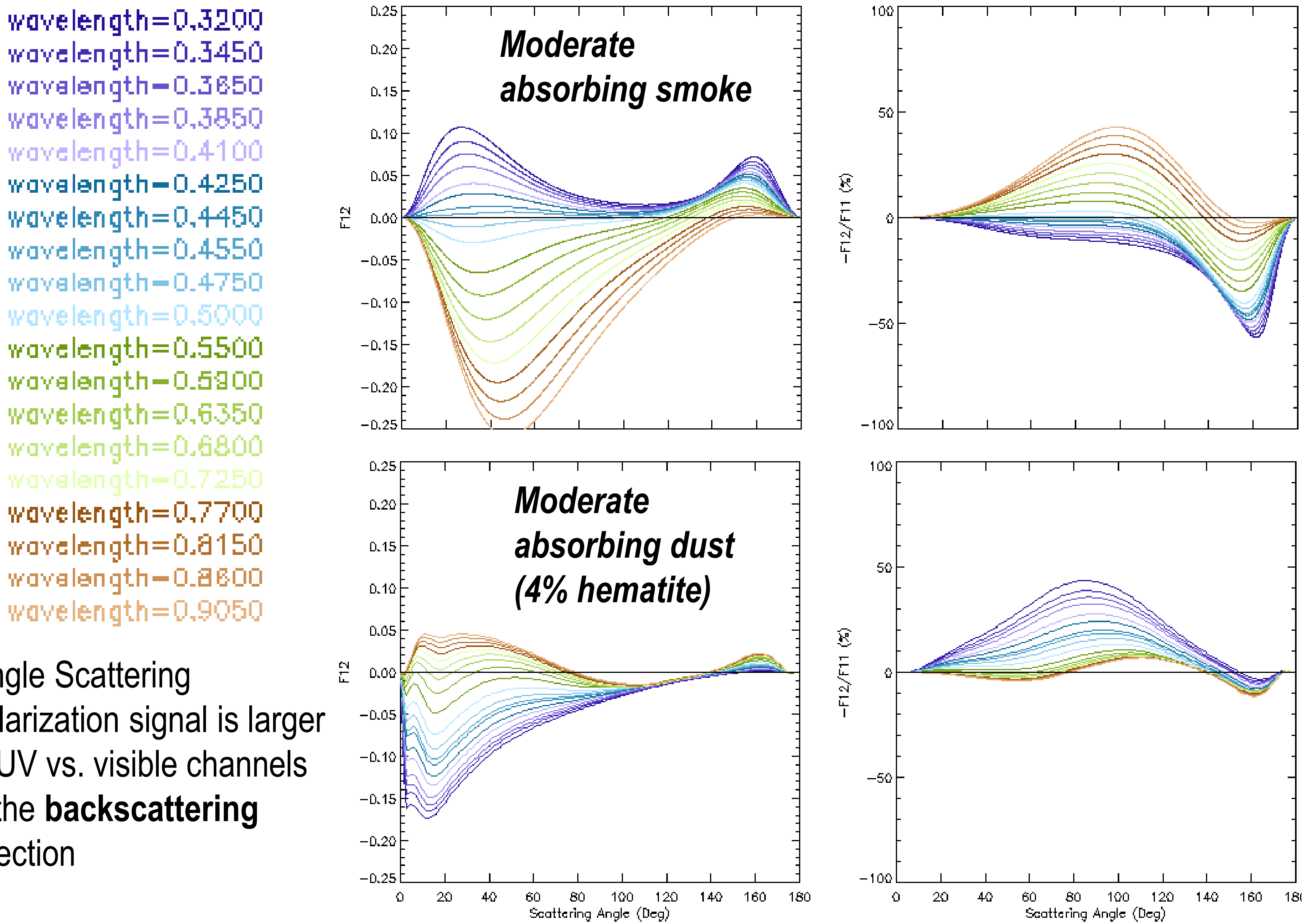
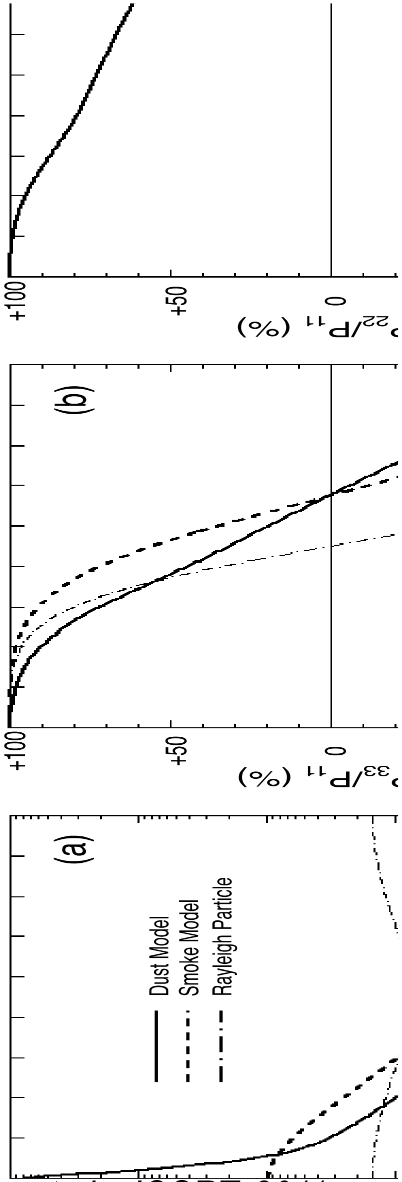
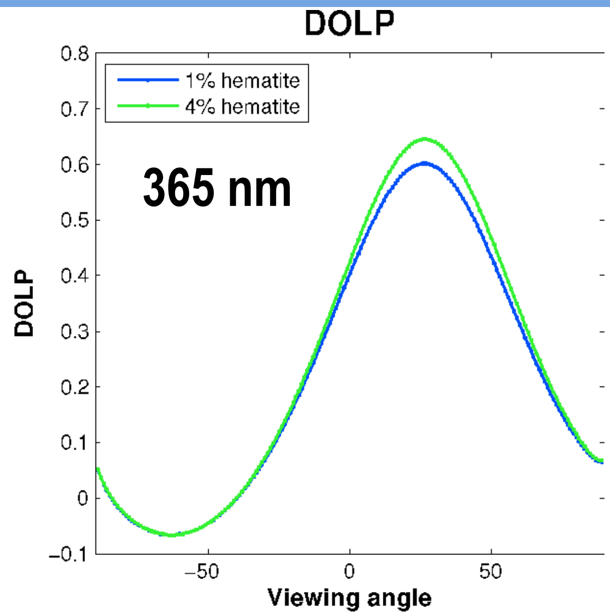
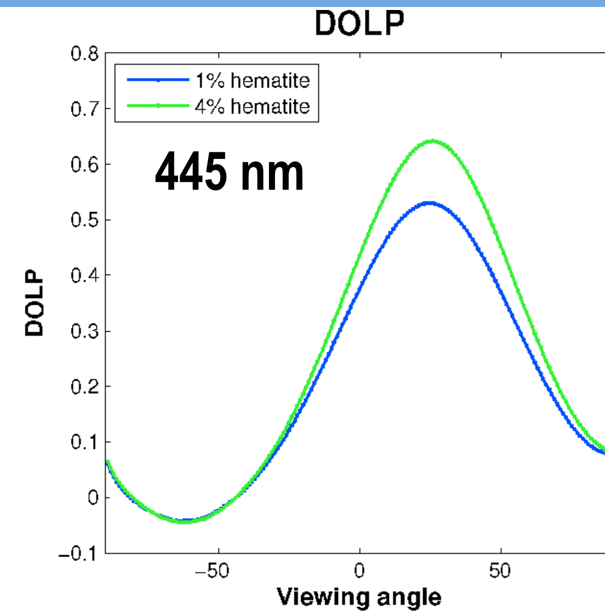


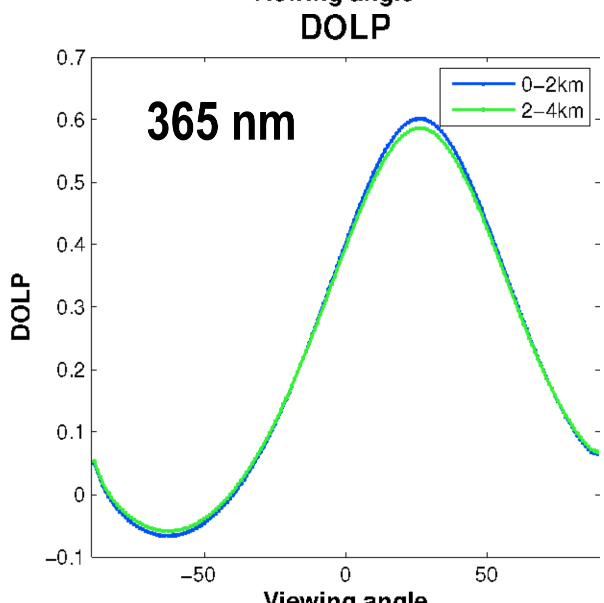
Single Scattering Polarization signal is larger at UV vs. visible channels in the **backscattering** direction

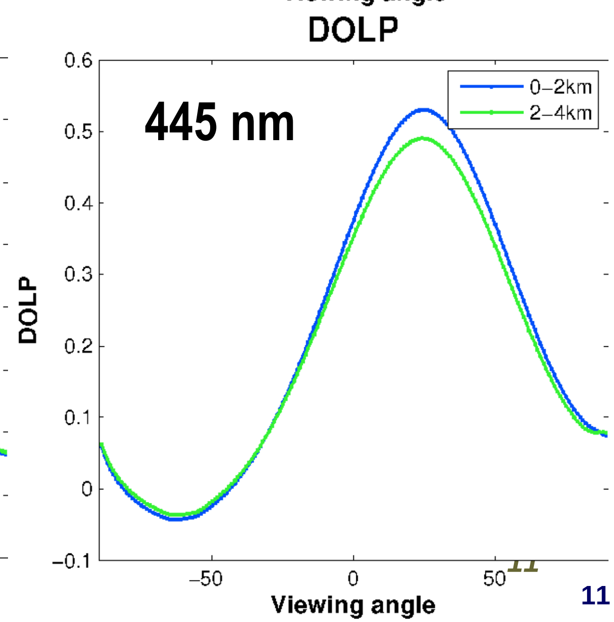
Rayleigh is polarizing!





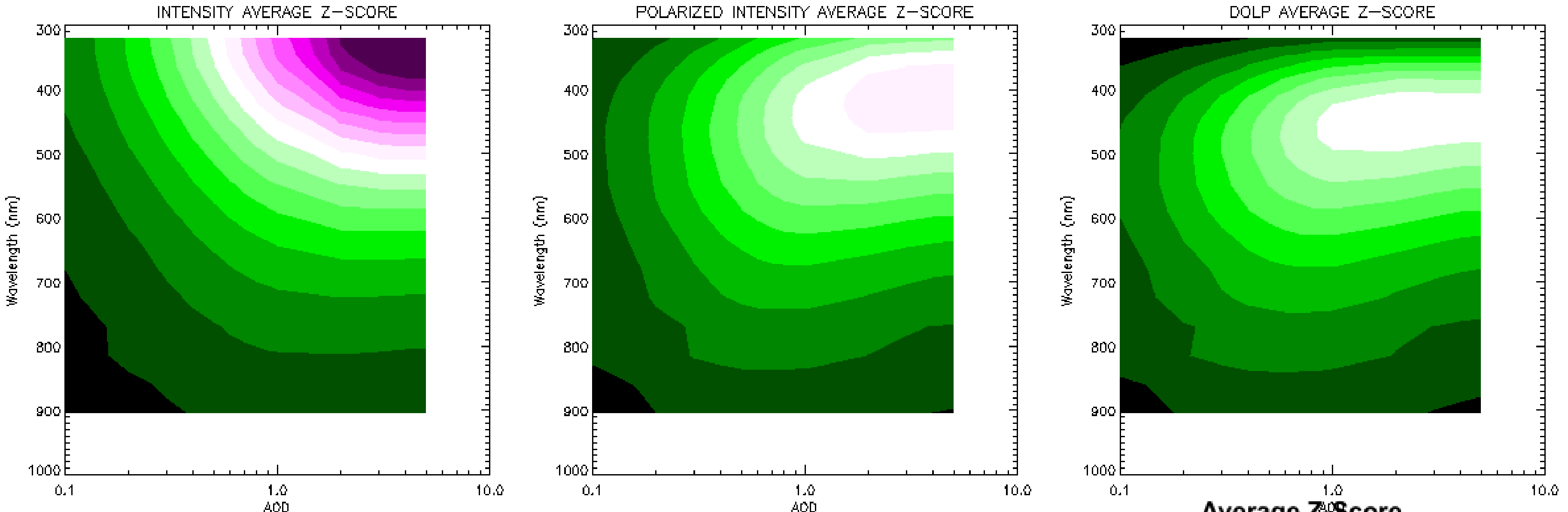


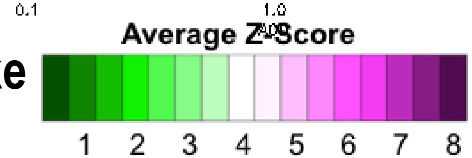




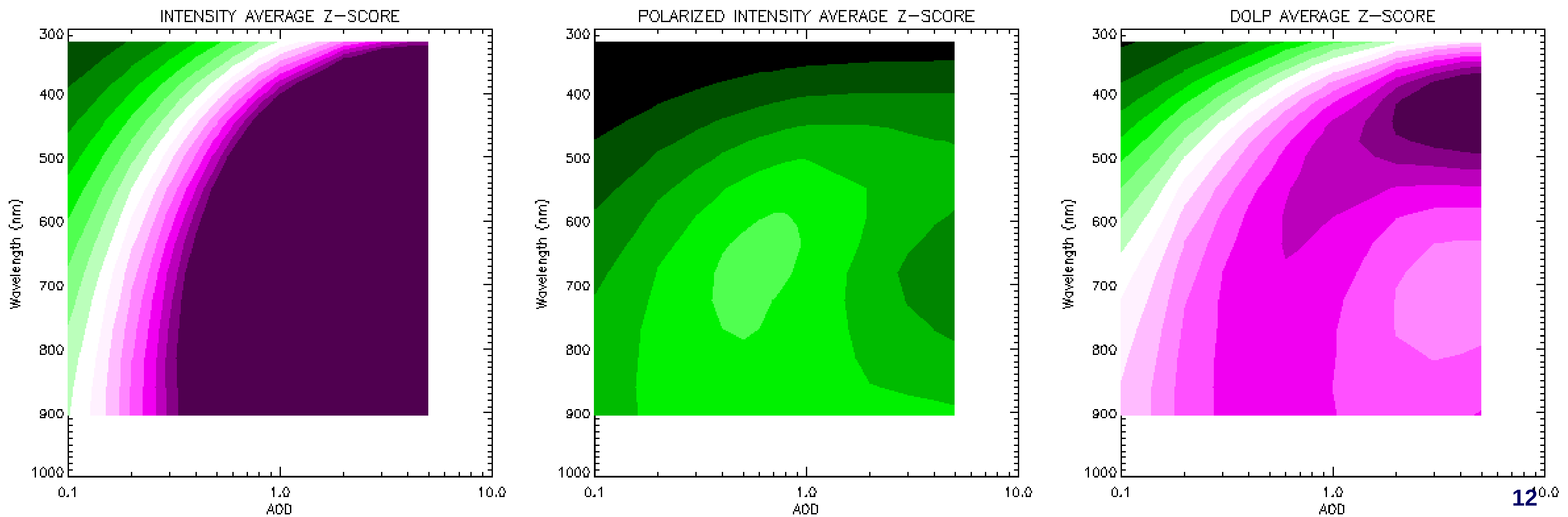
Kalashnikova et al., JQSRT, 2011

Polarimetric sensitivity to absorbing smoke height 2 km differences (0-2 vs. 2-4km layer)





Polarimetric sensitivity to moderately vs. weakly absorbing smoke SSA differences (SSA changed from 0.89 to 0.80 at 555 nm)



Discussion points on z-score sensitivity

The sensitivity studies were performed with the SOS code (*Zhai et al., 2010*) at JPL and by Pengwang Zhai for variety of absorbing aerosol models (weakly and moderate-absorbing smoke and dust) for black surfaces and Type-1 waters.

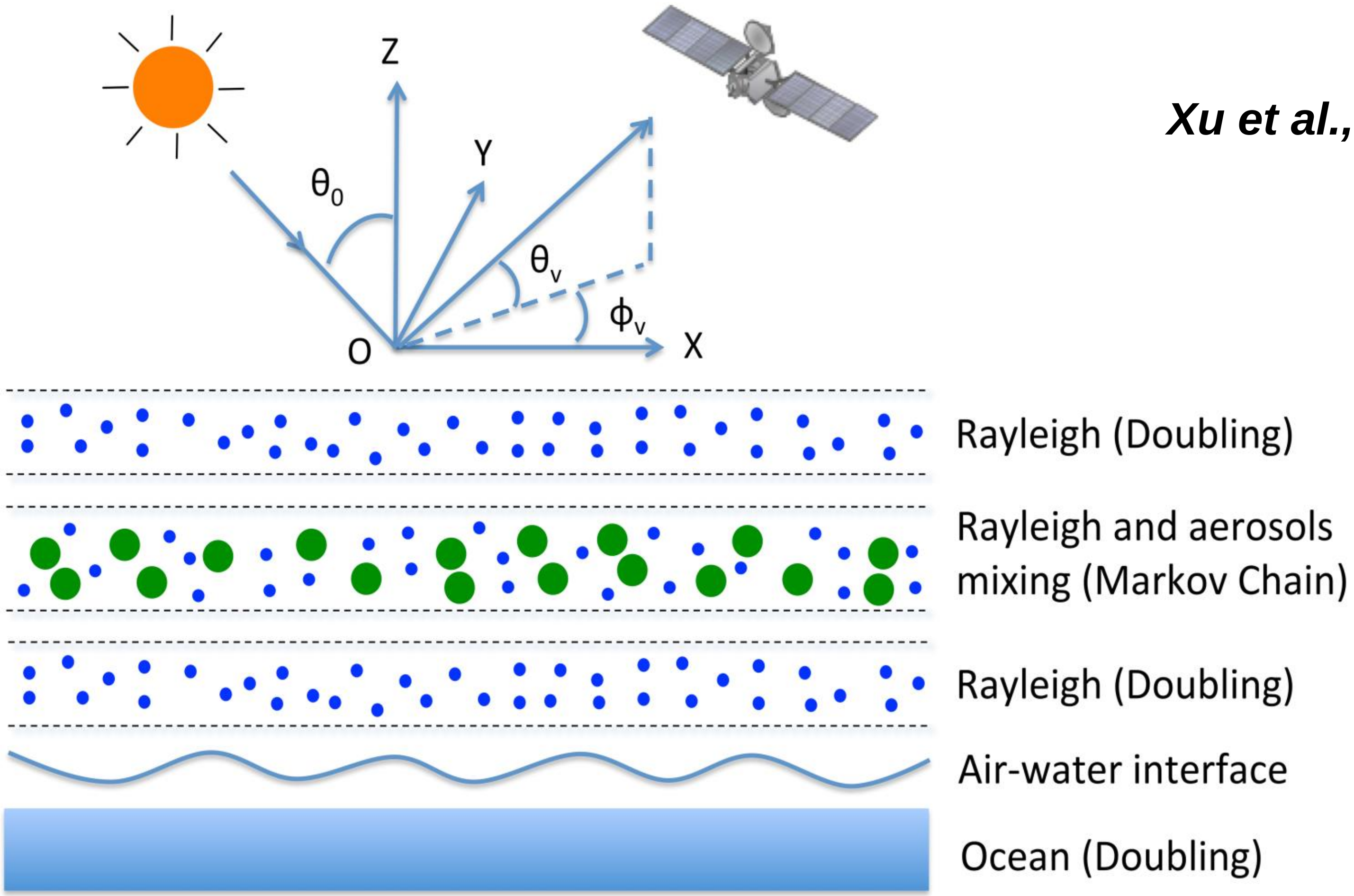
Initial conclusions: For an instrument with 1.5% uncertainty in intensity and 0.5% in DoLP (potential polarimeter candidate for PACE):

- The sensitivity to aerosol absorption and height is limited (Z-score is less than 3) for AOD<0.3; AOD above 0.2 is required for absorbing smoke property characterization
- Polarimetric UV channels are less sensitive to aerosol properties vs. polarimetric short-VIS channels as Rayleigh polarization suppresses smoke polarization signal in UV

Ongoing studies will quantify UV multiangle and polarimetric sensitivities in the presence of brown carbon (brown carbon model is adapted from Mok et al., 2016.)

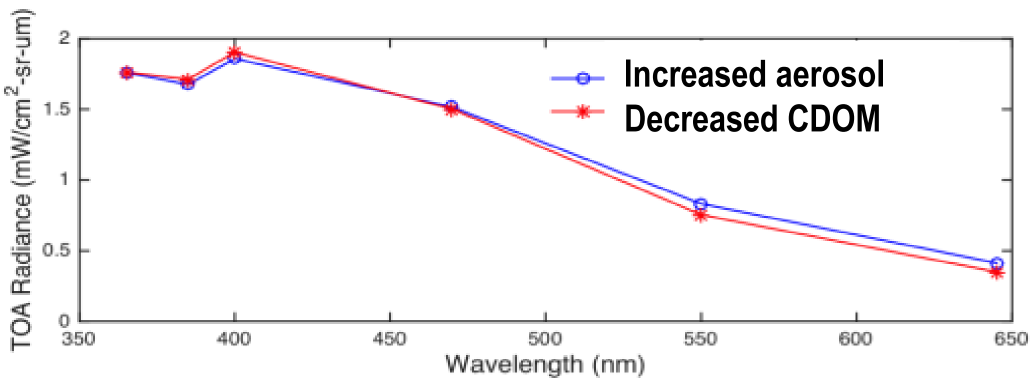
Coupled ocean-atmosphere RT model

Xu et al., 2016, AMT



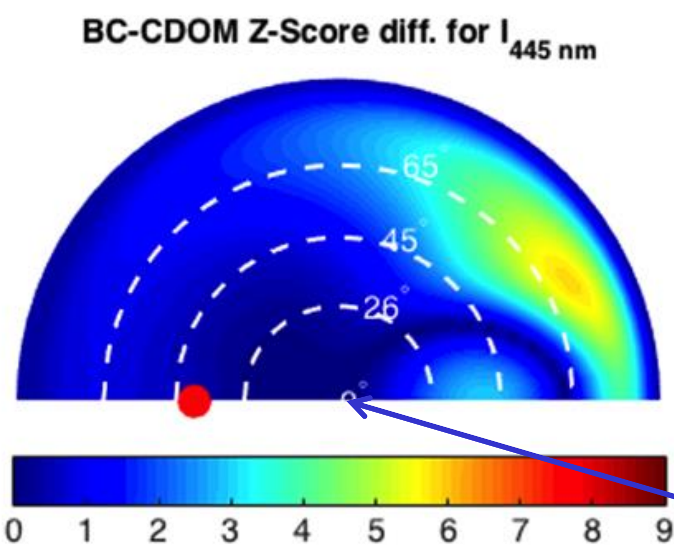
An optimization approach **has been developed** for simultaneous retrieval of aerosol properties and normalized water-leaving radiance (nL_w) from multispectral, multiagular, and polarimetric observations over ocean.

Distinguishability of atmospheric and oceanic absorption at certain viewing geometries

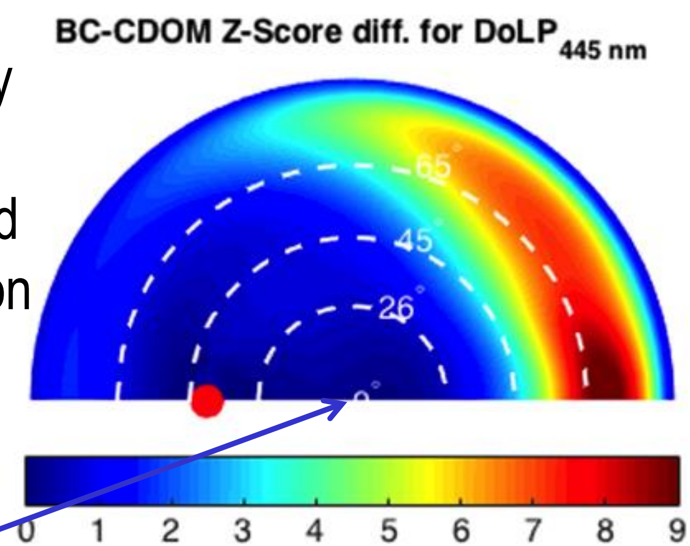


Markov Chain RT model; SZA: 40º
AOD = 0 to 0.1 (SSA = 0.95 at 445 nm)
CDOM absorption coeff. decreased from 0.04 m^{-1} (~Case 2 waters) to 0.004 m^{-1} at 470 nm (Case 1)
Wind speed 7 m/s, Chl-a concentration 0.3 mg/m^3
Size distribution based on Ahmad et al. (2010)
Fine mode (r_{eff} = 0.2 mm): brown carbon;
coarse mode: sea salt

Z-scores are the measurement differences divided by the measurement uncertainty.



The greatest distinguishability between atmospheric and ocean absorption is found at oblique angles



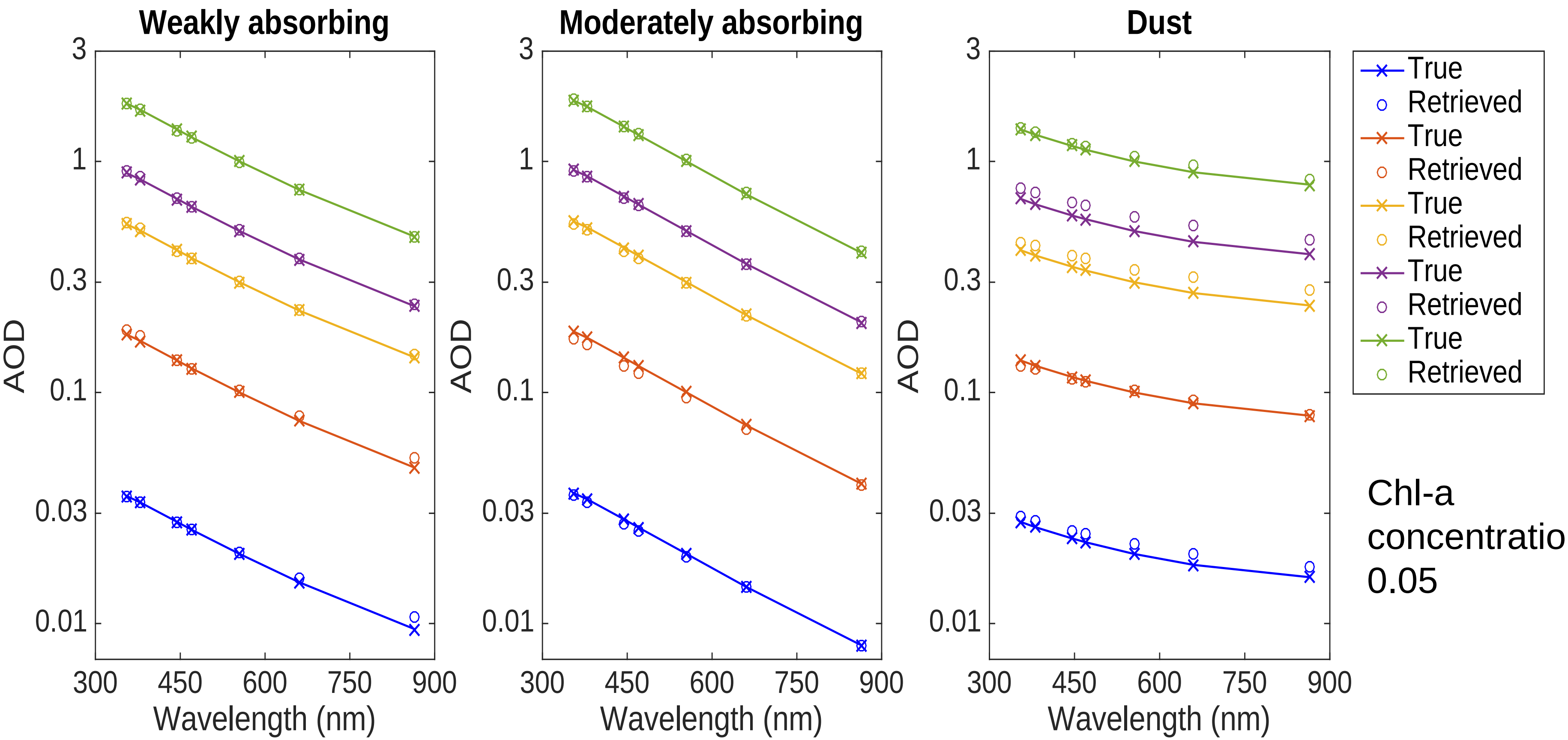
Not distinguishable with nadir view only

Retrieval sensitivities

- Aerosol heights: mixed within 1 km layer
- Bio-optical models: Type 1 waters
- Chl-a concentration: 0.05, 0.2, and 1.0 mg/m^3
- Spectral bands: 355, 385, 445, 475, 550, 660, and 865 nm
- AODs: 0.02, 0.1, 0.3, 0.5, 1.0; wind speed is 4 m/s
- Aerosol models: carbonaceous and dust
- 9 combinations of Sun illumination and viewing geometries
- ±10% perturbation on bio-optical model simulated nLw at 355, 385, 445, 475, and 550, 660, and 865 nm spectral bands

Xu et al., AMT, 2016

AOD

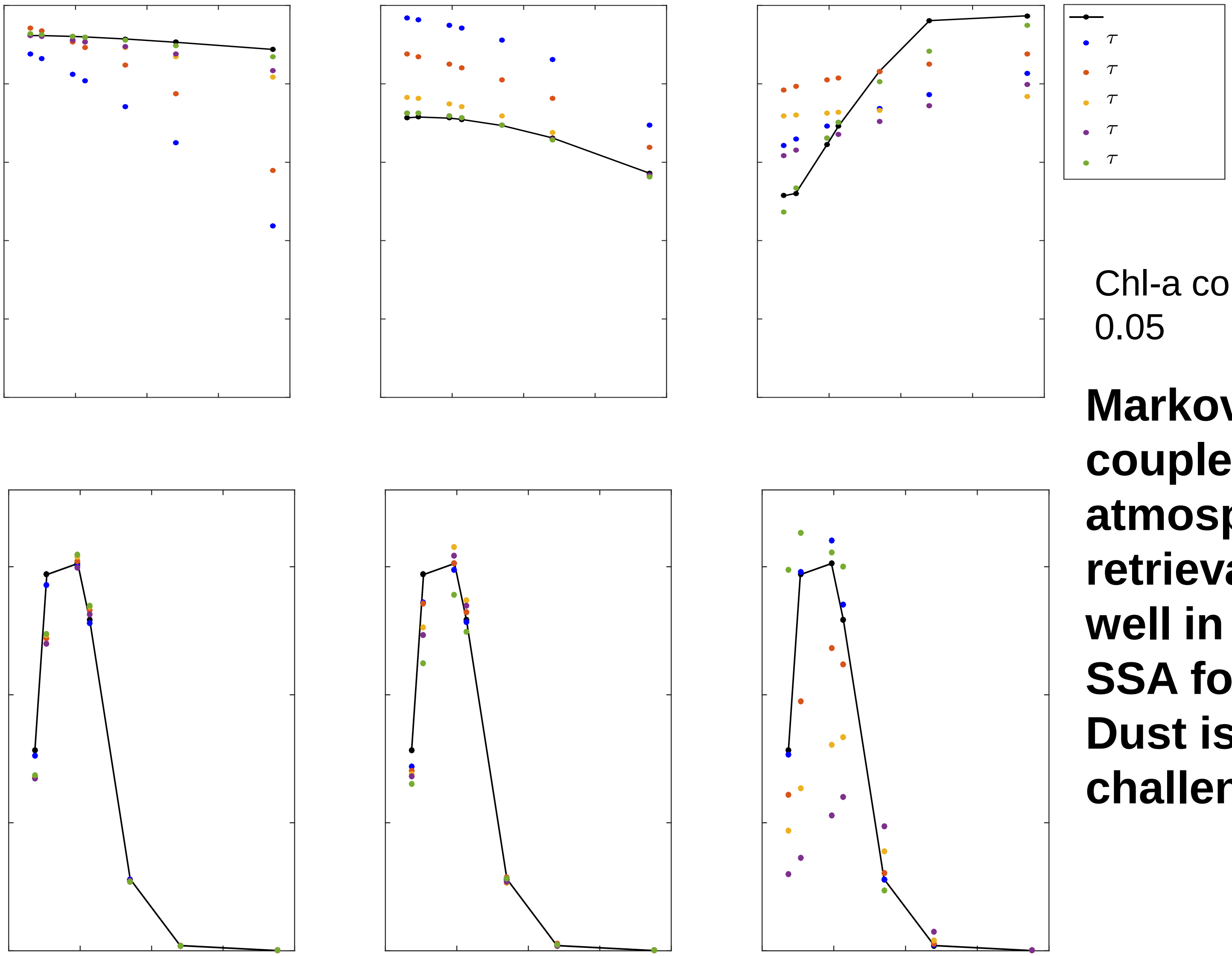


Chl-a concentration: 0.05

Xu et al., AMT, 2016

Markov-Chain coupled atmosphere ocean retrievals perform well in retrieving AOD in the presence of absorbing aerosols for all AOD ranges

SSA and water-leaving radiance



Xu et al., AMT, 2016

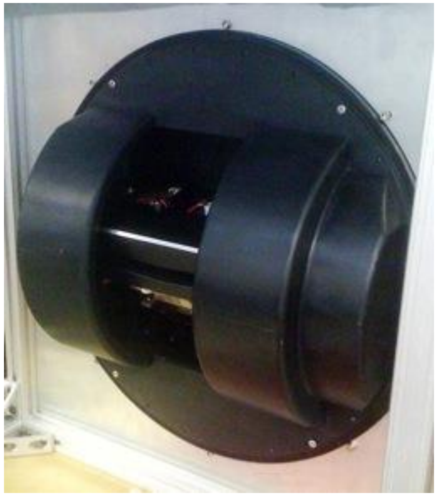
Chl-a concentration: 0.05

Markov-Chain coupled atmosphere ocean retrievals perform well in retrieving SSA for AOD >0.3. Dust is a particular challenge.

Discussion points for retrievability studies

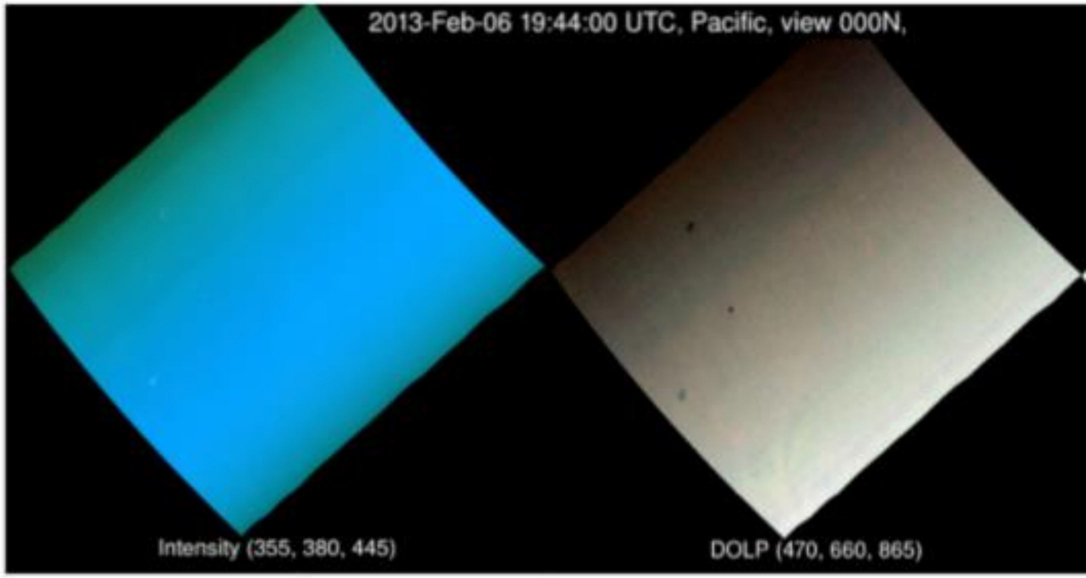
- Nadir top-of-atmosphere (1-angle) observations cannot distinguish UV-absorbing aerosols and CDOM
- At ~65º off-nadir, CDOM and aerosol absorption are distinguishable
- Markov-Chain coupled atmosphere ocean retrievals perform well in retrieving AOD in the presence of absorbing aerosols for all AOD ranges
- Truth-in/truth-out tests assuming random errors 1.0% (relative) and 0.005 (absolute) for intensity and DoLP, respectively, show that the retrieval accuracy of nL_w in the visible bands meet the requirements of the PACE SDT in the presence of weakly and moderately absorbing aerosols of optical depth at 555 nm less than 1 and Chl-a concentrations 0.05, 0.2 and 1 mg m^{-3}, whereas meeting the PACE SDT goals in the UV and for dust is more challenging *(Xu et al., 2016).*
- Retrieval accuracy of absorbing aerosol properties (including SSA) degrades for AOD below 0.3

Using AirMSPI to explore the value of a polarimeter

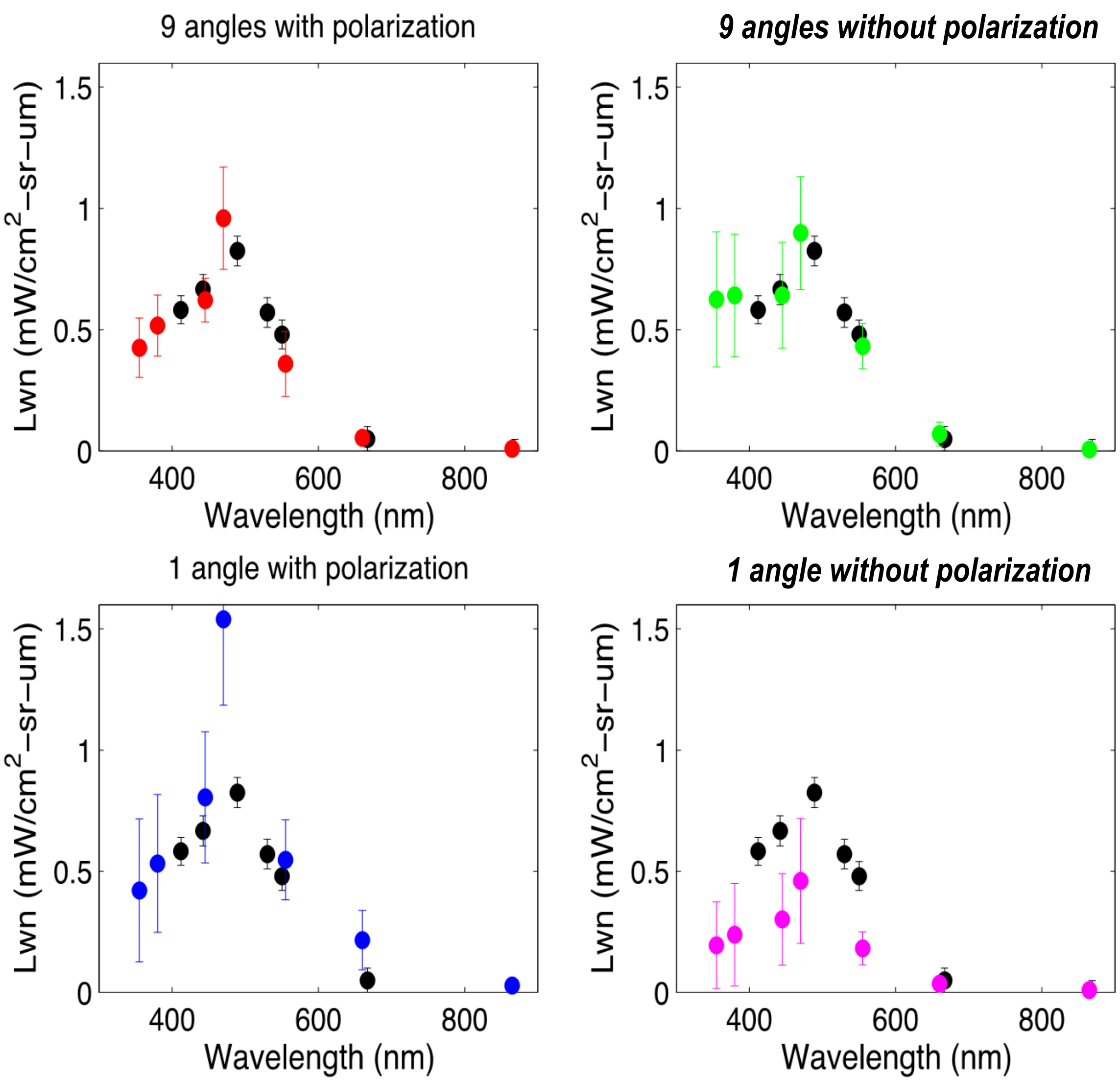


AirMSPI data were acquired over the USC SeaPRISM AERONET-OC site on the Eureka platform on February 6, 2013

Spectral bands	355, 380, 445, 470*, 555, 660*, 865*, 935 nm (*polarized)
Flight altitude	20 km
Multiangle viewing	Between ±67º using single-axis gimbal



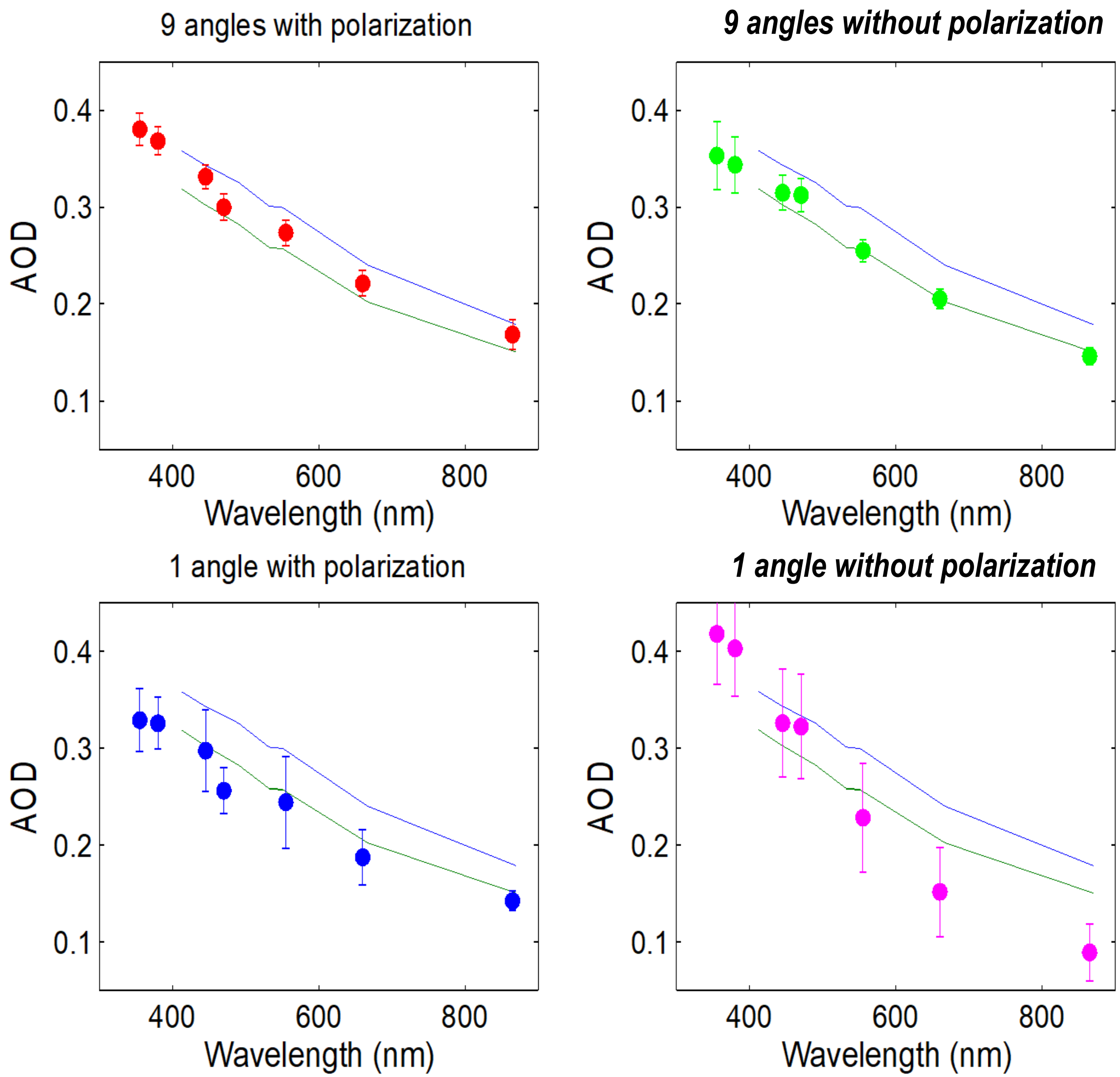
Normalized water-leaving radiance sensitivity to measurement information content (Feb 6. case)



- ❖ Colored symbols: Mean and spread of AirMSPI retrieval results based on 8 initial guesses.
- ❖ Blacks symbols: SeaPRISM observations with error bars denoting PACE SDT uncertainty target.

Non-absorbing aerosols

Aerosol optical depth retrieval sensitivity to measurement information content (Feb. 6 case)



- Colored dots: Mean AirMSPI retrieval results based on 8 initial guesses at 19:43 UTC.
- Colored error bars: Spread of these 8 results.
- Blue and green lines: SeaPRISM observation at 19:08 and 20:08 UTC.

Normalized water-leaving radiance sensitivity to measurement information content (UV-absorbing dust)

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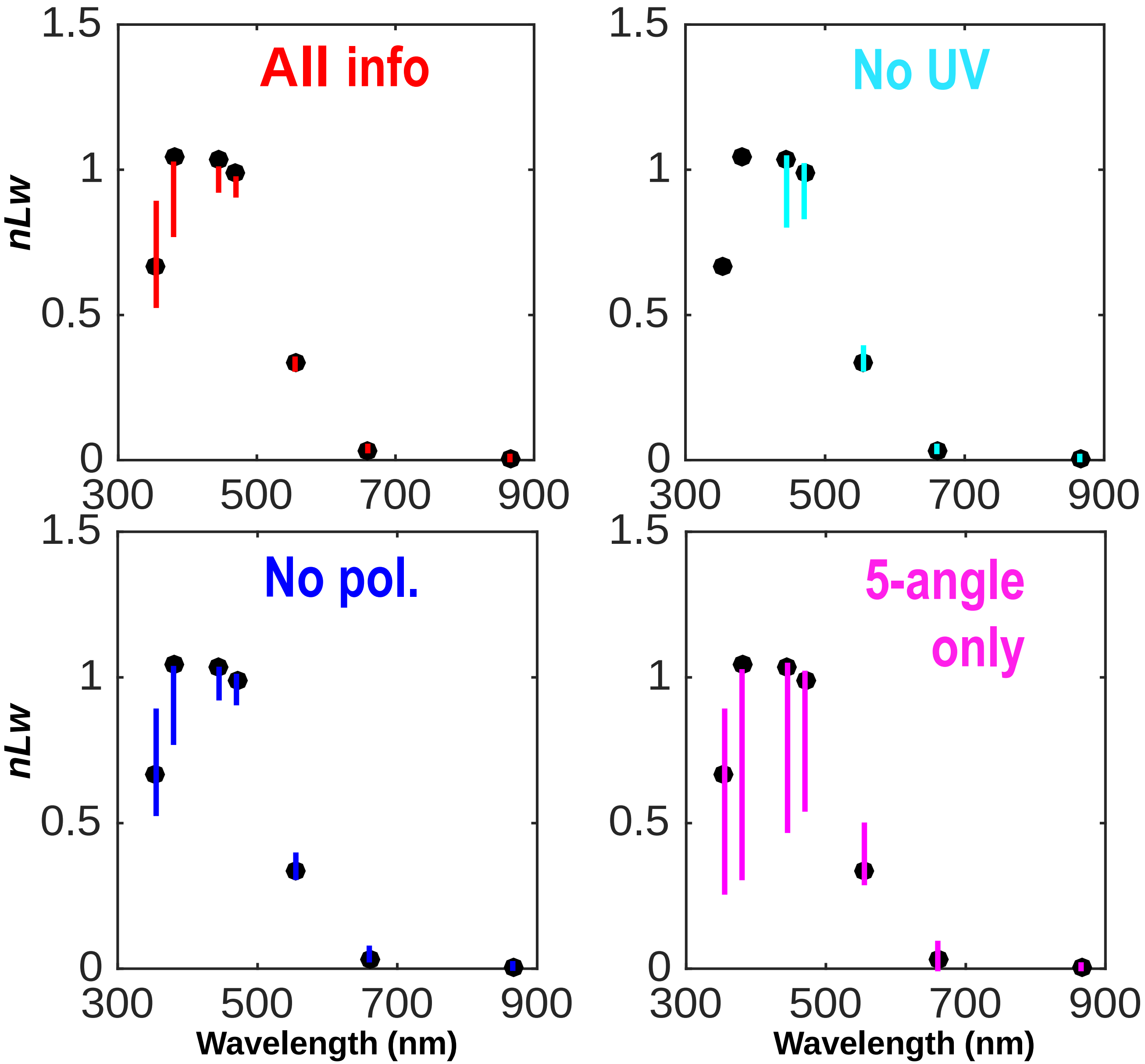
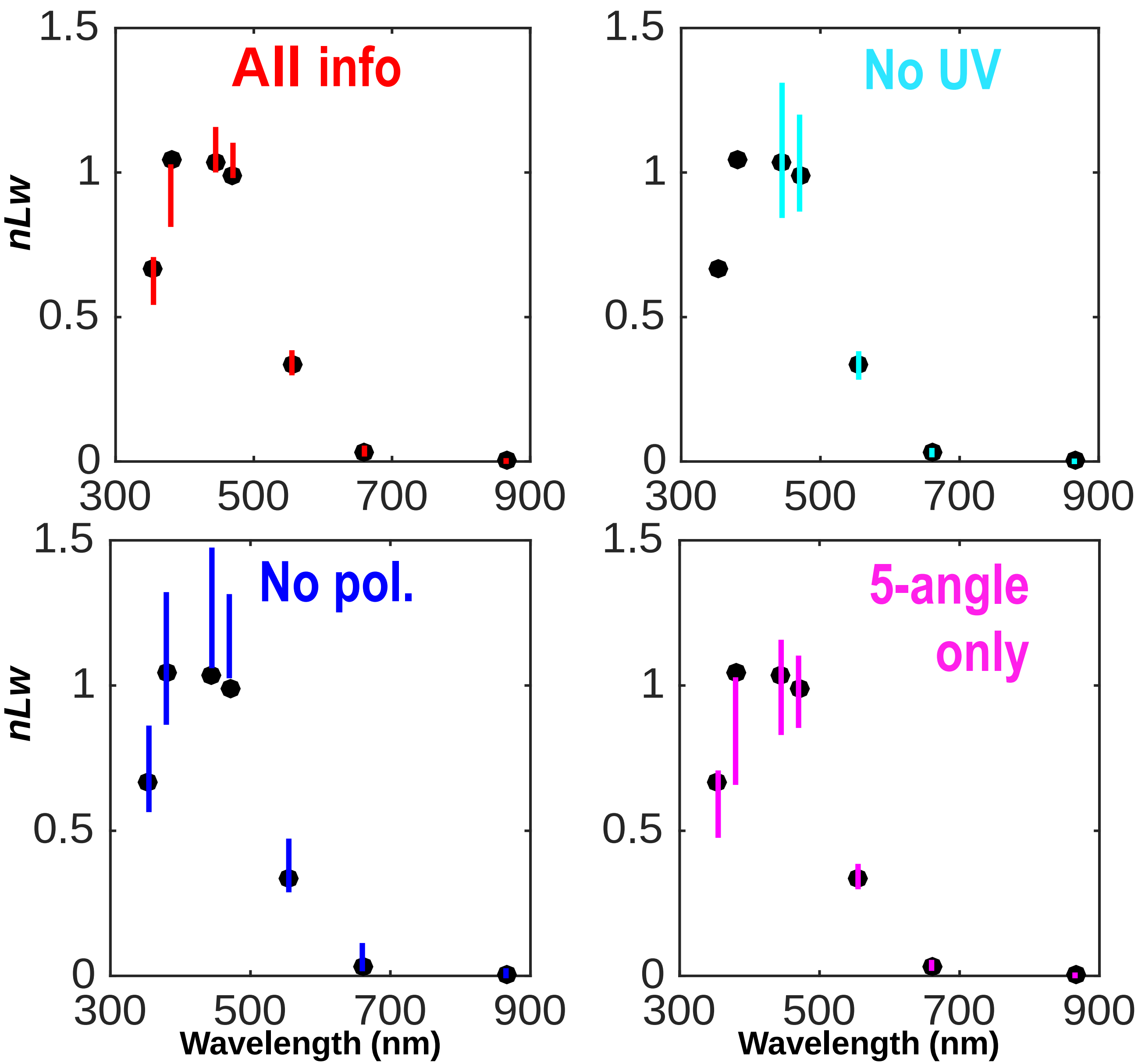


- USC_SeaPrism geometry of Sun incidence and viewing
- 1.5% relative error added to radiance
- 0.5% relative error added to DOLP
- 15 initial guesses
- 100 patches used to constrain the retrieval
- AOD = 0.3 at 555 nm [Chl_a] = 0.2 mg/m^3 with adjustment of +- 10%
- Type 1 waters

Normalized water-leaving radiance sensitivity to measurement information content (Absorbing smoke)



- USC_SeaPrism geometry of Sun incidence and viewing
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- 15 initial guesses
- 100 patches used to constrain the retrieval
- AOD = 0.3 at 555 nm [Chl_a] = 0.2 mg/m^3 with adjustment of +-10%
- Type 1 waters

Discussion points on information content of AirMSPI observations

- The exclusion of UV channels, and the reduced angular coverage degrades nL_w retrievals;
- The exclusion of polarization channels does not impact nL_w retrieval results in the presence of dust but significantly degrades retrievals for the moderately absorbing smoke;
- More cases of various viewing geometries and atmospheric conditions need to be considered.

AirMSPI retrieval validation

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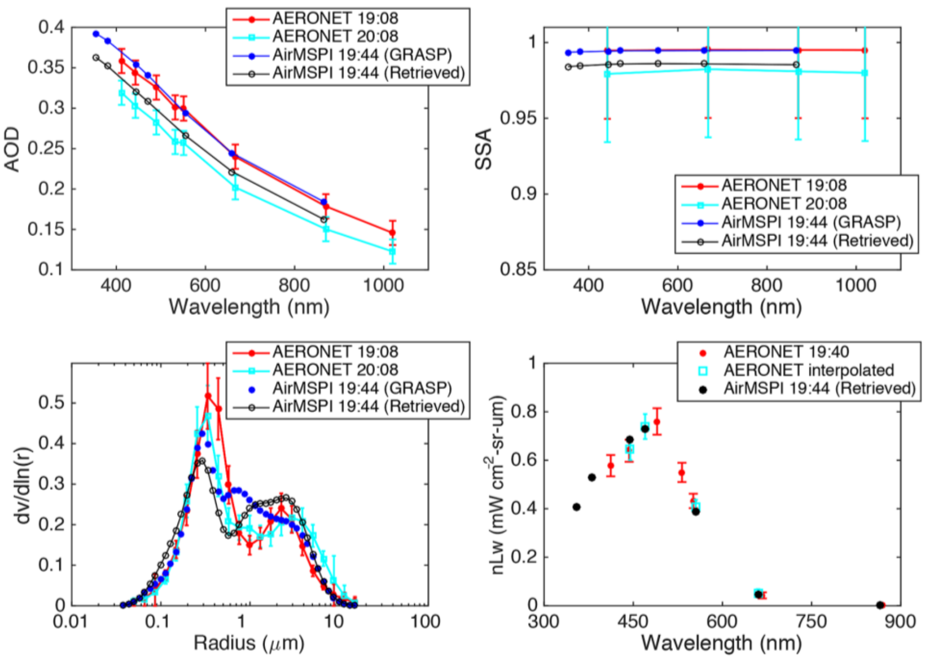
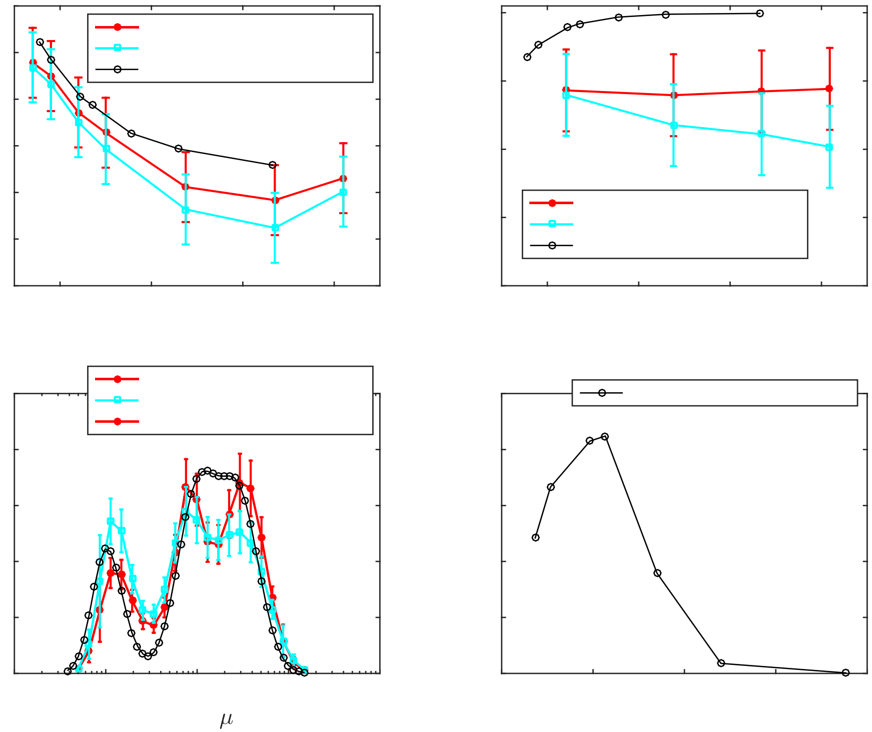
SeaPRISM, Feb. 6, 2013, 19:44 UTC

(from Xu et al., 2016)



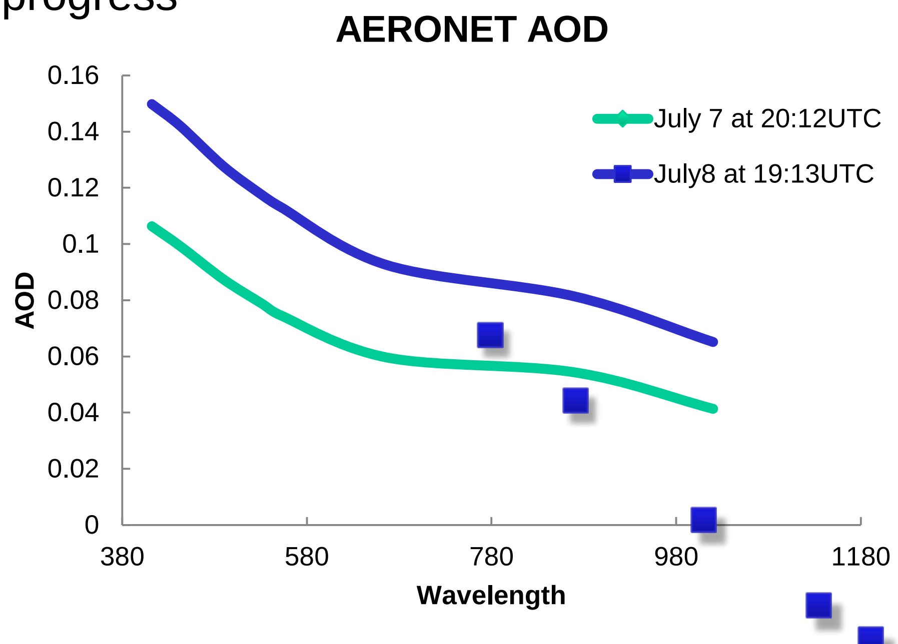
Monterey, Apr. 28, 2014, 17:25 UTC



- February 6, 2016 case study of AOD, SSA, size distribution and nL_w over the AERONET USC SeaPRISM OC site compares favorably to AERONET’s reported values;
- Aerosol property accuracy decreases at low AODs in the case of AirMSPI observations over AERONET Monterey site.

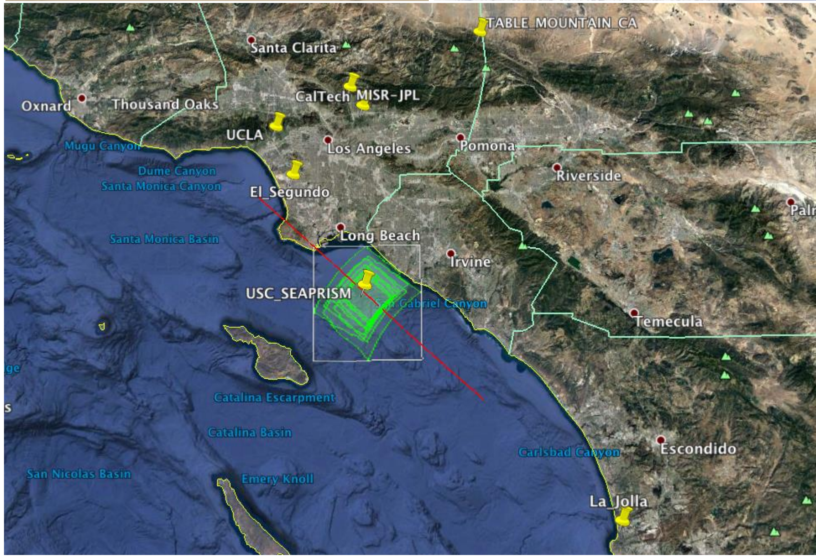
New AirMSPI data collection

- The Imaging Polarimetric Assessment and Characterization of Tropospheric Particulate Matter (ImPACT-PM) field campaign was accomplished on July 5-8, 2016
- Data were collected over USC SeaPrism AERONET ocean site on July 7 and 8, 2016
- SPEX data analysis and comparison with AirMSPI data were presented at Fall AGU 2016
- The AirMSPI data analysis is currently in progress



- **AirMSPI-1**
- **CPL**
- **SPEX**

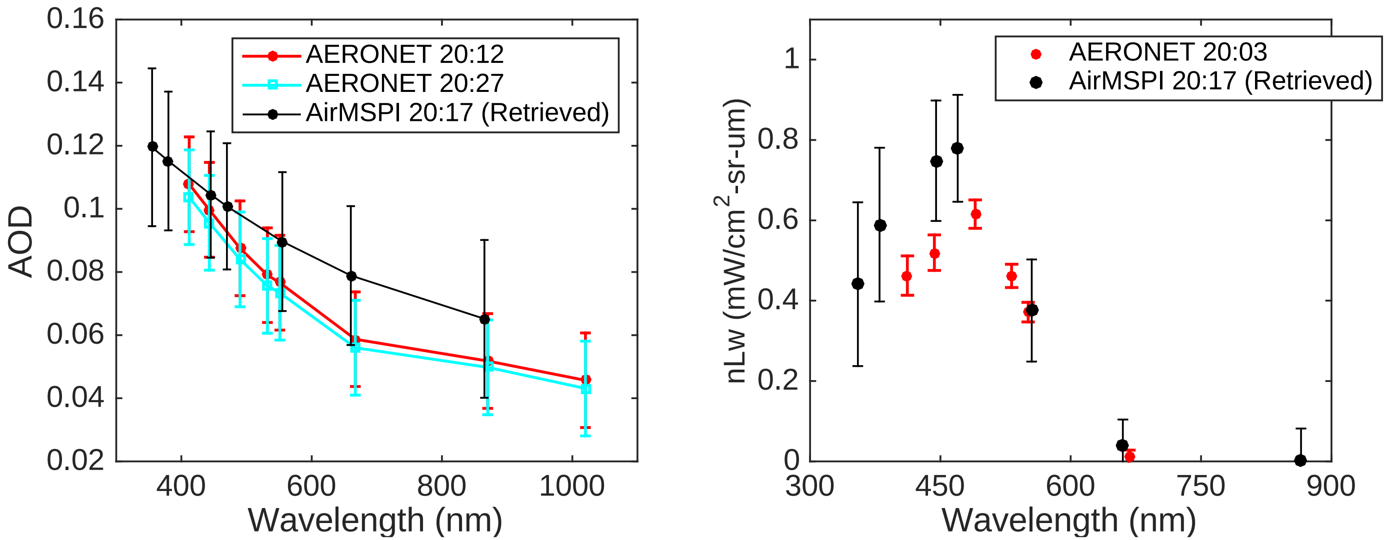
Role	Name
JPL PI	**Olga Kalashnikova**
Caltech PI	**John Seinfeld**



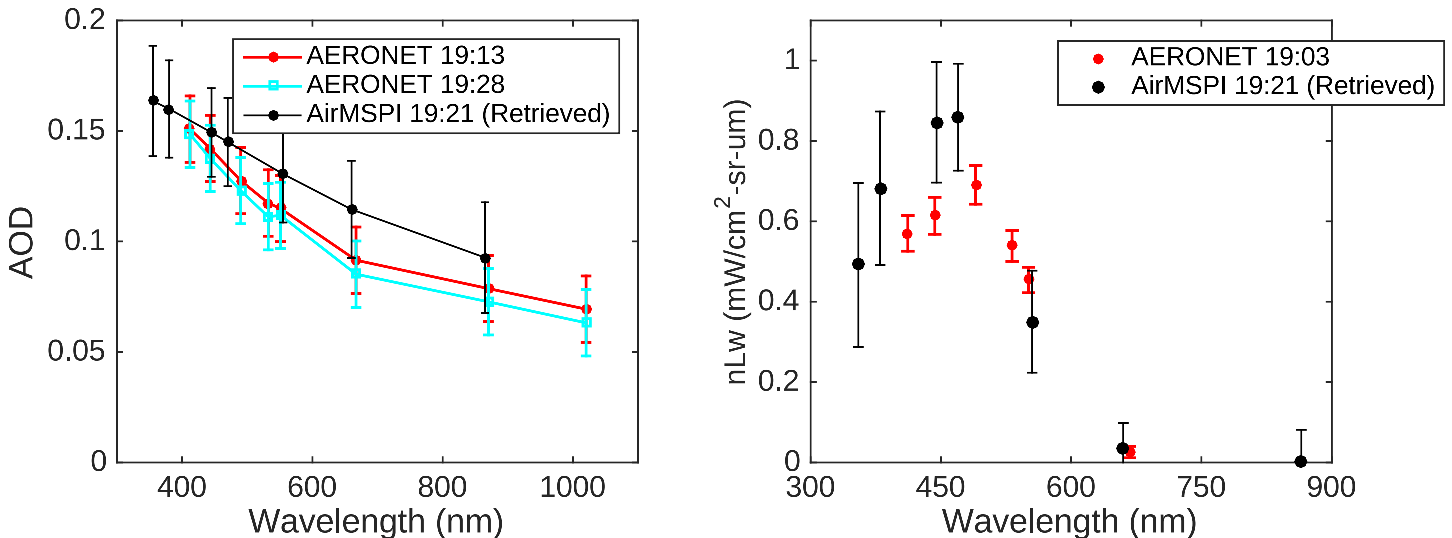
July 7, 2016: 20:11:06 UTC
July 8, 2016: 19:15:10 UTC

Initial validation of IMPACT-PM data

SeaPRISM, July 7, 2016, 20:11 UTC



SeaPRISM, July 8, 2016, 19:15 UTC



Discussion points on AirMSPI retrievals

- February 6, 2016 case study of AOD, SSA, size distribution and nL_w using real AirMSPI observations over the AERONET USC SeaPRISM OC site compare favorably to AERONET's reported values;
- Analysis and validation of AirMSPI observations collected at UCB SeaPRISM site in July of 2016 is work in progress;
- Development of a fast, yet accurate, RT model and algorithm validation using a wider set of AirMSPI scenes is also part of our ongoing effort.

Thank you!

Olga.Kalashnikova@jpl.nasa.gov

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